

## Optimizing Layer Configuration in Banana Bomb Blankets for Enhanced Blast Resistance

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Received 5 January 2026, Revised 16 February 2026, Accepted 11 March 2026

### ABSTRACT

*This study investigates the influence of layer configuration on the blast resistance of banana fiber bomb blankets, a sustainable alternative to conventional synthetic protective materials. Twill-woven banana fiber blankets were fabricated with varying numbers of layers ranging from one to five layers, while all other parameters were kept constant to isolate the effect of layer configuration. Controlled explosive blast tests were conducted, and the thermal response of each configuration was measured using Type-K thermocouples connected to a data logging system. The experimental results demonstrate that increasing the number of layers significantly enhances blast mitigation performance by reducing peak temperature transmission and improving energy dissipation across the blanket structure. Among the tested configurations, the five-layer banana bomb blanket exhibited the lowest thermal penetration and superior resistance to blast effects. These findings confirm that optimized multilayer stacking plays a critical role in improving blast resistance by promoting progressive energy attenuation. The five-layer configuration reduced peak temperature transmission from 387.89 °C to 114.80 °C, a 70% reduction, demonstrating superior blast-mitigation performance. The results highlight the potential of banana fiber bomb blankets as an eco-friendly and cost-effective solution for blast protection in industrial and safety-related applications.*

**Keywords:** Banana fiber, Blast resistance, Bomb blanket, Energy dissipation, Layer configuration.

### 1. INTRODUCTION

In recent years, research on natural fiber-based materials has gained considerable attention due to their potential applications in engineering and protective systems. Banana fiber is regarded as a promising natural fiber due to its favourable mechanical properties, low density, environmental sustainability, and cost-effectiveness compared to conventional synthetic fibers [1]. These characteristics make banana fiber suitable for advanced applications that require lightweight, eco-friendly materials.

Despite these advantages, the performance of banana fiber under extreme loading conditions, such as explosive blast pressure, has not been extensively investigated [2]. Blast events generate high-pressure shockwaves and elevated temperatures that can significantly damage conventional materials, underscoring the need for alternative materials that can effectively absorb and dissipate energy [3]. Evaluating the structural integrity and energy absorption behaviour of banana fiber under blast loading is therefore essential to determine its suitability for blast-resistant applications [4, 5]. When properly engineered, natural fiber systems can provide acceptable mechanical performance while reducing environmental impact. In blast protection

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systems, structural parameters such as layer configuration play a critical role in controlling shockwave propagation, thermal attenuation, and overall energy dissipation [6].

Optimizing the layer configuration of banana fiber bomb blankets can enhance blast mitigation performance by promoting progressive energy absorption across multiple layers and reducing peak temperature transmission [7, 8]. This study evaluates the effect of layer configuration on the blast resistance of banana fiber bomb blankets. By systematically varying the number of layers while maintaining constant material and weave parameters, the influence of multilayer stacking on thermal response and blast mitigation performance is examined.

## 2. MATERIAL AND METHODS

Banana fibers were obtained from mature banana pseudostems sourced locally in Malaysia. The fibers were woven into fabric using a twill weave pattern, which has been reported to provide improved flexibility and resistance to tearing under dynamic and impact loading conditions [9].

### 2.1 Banana Fiber Preparation

Banana fibers were manually extracted from the pseudostem trunk of mature banana plants. The extracted fibers were thoroughly washed with tap water to remove residual sap, dust, and surface impurities, following commonly reported preparation procedures for natural fiber composites. The fibers were then air-dried at ambient conditions until a constant mass was achieved to ensure consistent moisture content prior to fabrication.

After drying, the fibers were aligned and woven into a twill woven pattern as shown in Figure 1, using identical weaving parameters to maintain uniform fabric quality across all specimens. The woven banana fiber blanket was subsequently cut into standard dimensions of 30 cm × 30 cm, ensuring consistent geometry and structural uniformity for all blast test samples.



Figure 1: Twill-woven banana fiber blanket.

### 2.2 Bomb Blanket Layer Configuration

Banana bomb blankets were fabricated using five different layer configurations, such as one-layer, two-layer, three-layer, four-layer, and five-layer assemblies. Each layer was stacked uniformly with consistent fiber orientation and alignment [10]. The stacking sequence was kept identical for all specimens to eliminate variability due to orientation effects.

All bomb blanket samples were prepared without additional adhesives or resin matrices, allowing the assessment to focus solely on the influence of multilayer stacking on blast resistance performance.

### 2.3 Test Setup

The blast experiment was conducted in a controlled outdoor testing area on level ground. The explosive charge was positioned at the centre of a circular steel platform to ensure stable and fixed placement during detonation. A remote detonation system was used to initiate the explosion, and the relative position between the explosive charge and the test specimen was maintained constant for all tests.

For temperature measurement, a confined space was prepared beneath the banana bomb blanket specimen. Type-K thermocouples were installed inside the confined space to measure temperature transmission during blast exposure. The thermocouple sensing junctions were positioned at different locations within the confined space, while the thermocouple wires were routed away from the blast zone and connected to a data acquisition system located at a safe distance.

A twill-woven banana bomb blanket specimen was placed directly on top of the confined space, fully covering the thermocouples. The blanket was laid flat to ensure uniform exposure to the blast wave. The orientation, placement, and distance between the explosive charge, banana bomb blanket, and confined space were kept identical for all experiments to ensure repeatable testing conditions.

All sensors and measuring devices were activated prior to detonation to establish baseline readings. Temperature data were recorded continuously during each blast event. The same experimental arrangement was used for all layer configurations to allow direct comparison of blast response. The overall setup is illustrated in Figure 2. Multiple thermocouples were positioned at different locations within the confined space to capture spatial temperature variations and improve measurement reliability and repeatability.



**Figure 2:** The setup for the blast test. (a) Placement of thermocouples inside the confined space and (b) Arrangement of the banana bomb blanket specimen during blast testing.

### 3. RESULTS AND DISCUSSION

#### 3.1 Blast Temperature of Banana Bomb Blankets

The blast test findings indicate that the layer arrangement in banana bomb blankets significantly influences their thermal blocking efficiency. As shown in Table 1, the maximum temperature in the confined space decreased with increasing layer number. This trend indicates that multilayer stacking enhances the effectiveness of banana bomb blankets in reducing blast-induced thermal transmission, which is consistent with previous studies on multilayer protective systems under explosive loading [11, 12].

The single-layer configuration exhibited a maximum temperature of 387.89 °C, indicating poor resistance to heat penetration during the blast. This behavior can be attributed to the insufficient thickness and limited energy-absorption capacity of a single woven layer, which allows substantial thermal transfer into the confined space [13]. The addition of a second layer resulted in a nearly 48 % reduction in peak temperature, demonstrating a significant improvement in thermal insulation and blast energy attenuation.

The three-layer and four-layer configurations exhibited further reductions in peak temperature, recording values of 160.64 °C and 135.89 °C, respectively. These results indicate that increasing the number of layers increases the blanket's effective thickness and introduces additional fiber interfaces that disrupt heat transfer and promote the gradual dissipation of blast energy. Similar behaviour has been reported in multilayer composite structures, where interlayer interactions play a critical role in thermal and energy attenuation mechanisms [14].

The five-layer banana bomb blanket recorded the lowest peak temperature of 114.80 °C, indicating superior thermal resistance and blast mitigation capability. This enhanced performance is attributed to increased energy absorption and redistribution across multiple layers. The twill weave structure further contributes to this behaviour by providing flexibility and resistance to localized fiber damage under dynamic blast loading.

The findings indicate that optimizing the layers in banana fiber bomb blankets markedly enhances blast resistance by reducing thermal penetration. The results validate that a refined five-layer setup provides enhanced blast-mitigation capabilities and underscore the promise of banana fiber as an eco-friendly substitute for blast protection [15, 16].

**Table 1:** Temperature recorded by three thermocouples for different banana bomb blanket layer configurations.

Layer configuration	Channel 1 (°C)	Channel 2 (°C)	Channel 3 (°C)	Peak Temperature (°C)
1	372.45	387.89	365.72	387.89
2	195.63	202.81	188.94	202.81
3	152.38	160.64	147.91	160.64
4	128.54	135.89	124.76	135.89
5	108.62	114.80	105.37	114.80

#### 3.2 Post-Blast Damage Observation of Banana Bomb Blankets

Visual examination of the banana bomb blanket specimens after blast exposure reveals a clear relationship between layer configuration and structural integrity. As illustrated in Figure 3, increasing the number of layers from 1 to 5 resulted in progressively reduced fiber damage and improved structural stability. These observations support the temperature measurements and

provide qualitative evidence of effective blast energy dissipation through multilayer stacking [14].

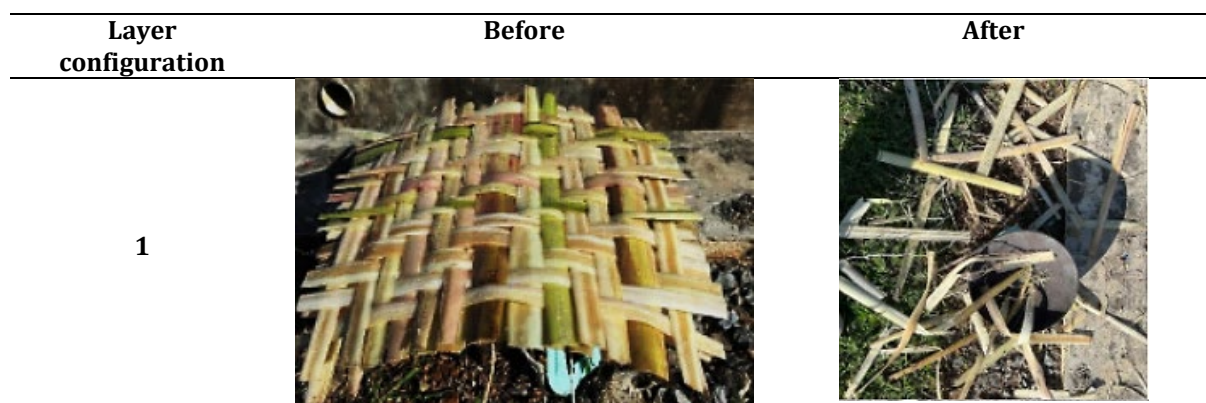
The single-layer configuration exhibited severe fiber fragmentation and extensive disintegration following blast exposure. The scattered, broken fibers indicate that the single-layer blanket was ineffective at absorbing or redistributing blast energy. This behaviour corresponds with the high peak temperature recorded for this configuration, suggesting significant transmission of both thermal and mechanical energy through the blanket [15, 16].

Partial structural retention was observed in the two-layer and three-layer configurations. Although fiber breakage and localized damage were present, a larger portion of the woven structure remained intact compared to the single-layer specimen. The reduced level of fragmentation indicates enhanced energy absorption and improved shielding provided by the additional layers. These visual observations are consistent with the lower temperature values recorded for these configurations, reflecting improved thermal attenuation.

The four-layer configuration demonstrated a notable improvement in post-blast structural stability. The woven structure largely maintained its original form, with only limited fiber bending and breakage observed. The reduced damage suggests that blast energy was distributed more uniformly across multiple fiber interfaces, reducing stress concentration and limiting heat transfer to the protected region [17].

The five-layer banana bomb blanket exhibited the highest resistance to blast effects, showing minimal visible damage after testing. The woven structure remained largely intact, and fiber fragmentation was significantly reduced. This superior performance is attributed to the increased effective thickness and multiple interlayer contacts, which promote progressive energy attenuation and restrict thermal penetration [18]. The observed structural integrity aligns with the lowest recorded peak temperature, confirming the enhanced protective capability of the five-layer configuration.

Overall, the visual damage assessment supports the quantitative temperature results, demonstrating that increasing the number of layers significantly enhances blast resistance. Multilayer banana bomb blankets effectively dissipate blast-induced energy through enhanced structural stability and fiber interactions, highlighting the importance of layer optimization in the design of durable, sustainable blast protection systems [19, 20].



**Figure 3:** Post-blast condition of banana bomb blankets with different layer configurations.

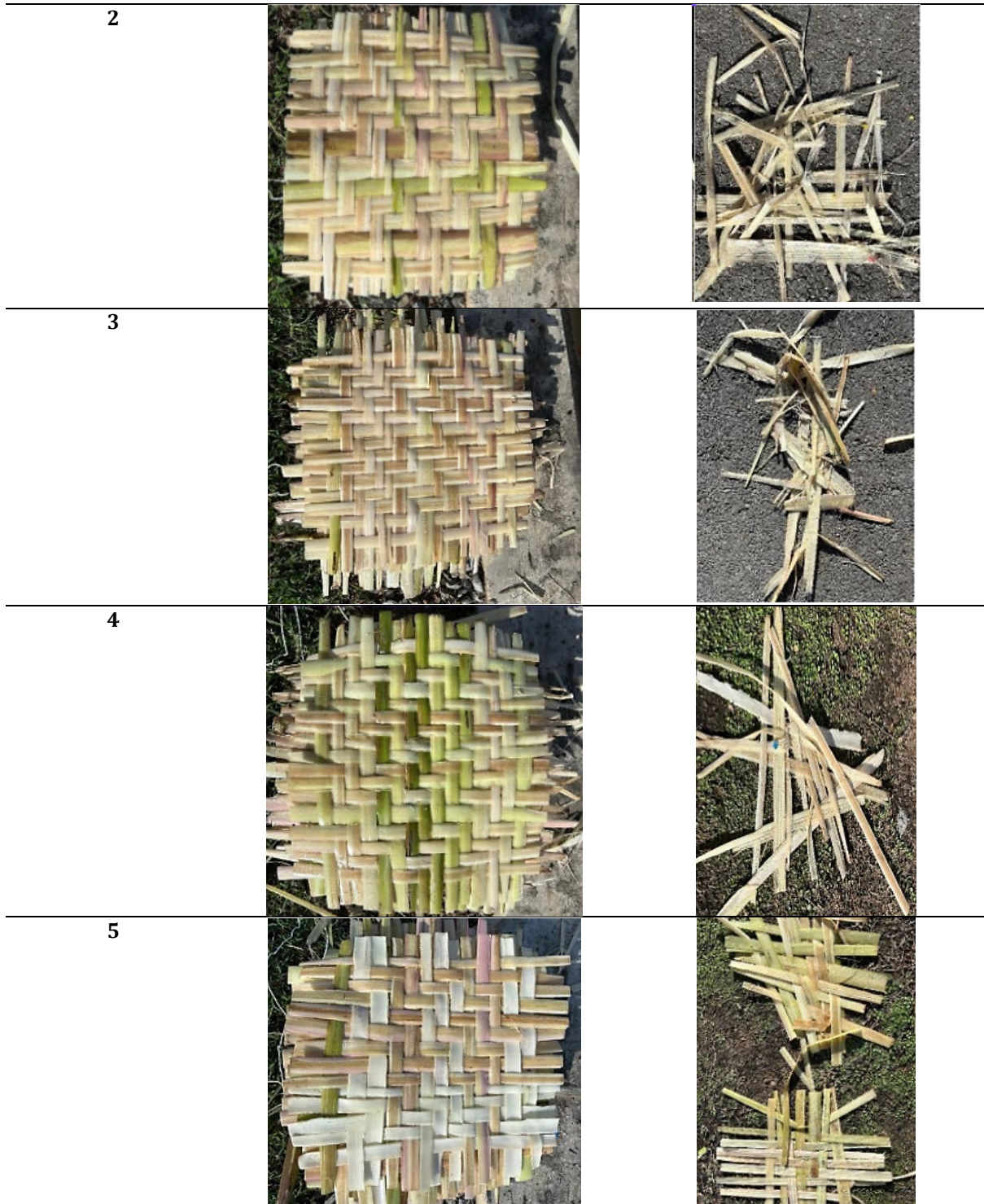


Figure 3: Continued.

#### 4. CONCLUSION

This study evaluated the blast-resistance effectiveness of banana fiber bomb blankets with different layer configurations using temperature assessment and post-blast damage analysis. The results demonstrate that the layer arrangement significantly influences the ability of banana bomb blankets to reduce thermal energy generated by blasts.

The application of Type-K thermocouples for temperature measurement in confined spaces showed that the peak temperature decreased with increasing layer count. The single-layer configuration exhibited optimal temperature transfer, suggesting a lack of blast protection. Conversely, multilayer configurations were more effective in preventing heat dispersion. The five-layer banana bomb blanket exhibited the lowest peak temperature, indicating superior effectiveness in blast mitigation.

Visual observations following the blast further corroborated the temperature results. Lower-layer designs exhibited significant fiber breakage and structural degradation, whereas higher-layer configurations maintained superior structural integrity. The five-layer configuration exhibited minimal visible damage, indicating that energy dissipation occurred and that the explosion's impact was mitigated by the layered stacking.

The findings indicate that modifications to the layer structure significantly enhance the blast resistance of banana fiber bomb blankets. Multilayer banana fiber constructions serve as a viable, durable, and cost-effective alternative to conventional blast-resistant materials for defensive applications. Future research may focus on optimizing thickness, weave patterns, and chemical treatments to improve blast mitigation effectiveness. This study demonstrates the efficacy of multilayer twill-woven banana fiber blankets as a sustainable blast-mitigation technology. The study presents experimental evidence that optimal layer stacking markedly improves thermal attenuation and structural stability, offering a cost-effective, environmentally friendly alternative to traditional synthetic blast protection materials.

## ACKNOWLEDGEMENTS

This research is supported by the Ministry of Higher Education, which provides a research grant through the Fundamental Research Grant Scheme (FRGS) under grant number FGRS/1/2023/STG05/UNIMAP/02/8. The authors also acknowledge the Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis (UniMAP) for the lab facilities.

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**Conflict of interest statement:** The authors declare no conflict of interest.

**Author contributions statement:** Conceptualization, S.A. and M.H.; Methodology, S.A.; Formal analysis, S.A.; Investigation, S.A.; Data curation, S.A.; Writing – original draft preparation, S.A.; Writing – review and editing, S.A., M.H. and A.R.; Visualization, S.A.; Supervision, M.H. and A.R.; Project administration, M.H. The authors have read and agreed to the published version of the manuscript.